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Factors affecting basin type solar still productivity: A detailed review

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ABSTRACT

Reasonable amounts of fresh water can be produced via inexpensive and sturdy solar stills in places that are exposed to solar radiation and have a brackish water. This work intends to analyze the many studies on factors that affect the performance of solar stills. The results showed that the distillation productivity of solar stills are significantly influenced by ambient conditions (e.g., ambient temperature, insolation, wind velocity, dust and cloud cover), operating conditions (e.g., depth of water, various dyes, salt concentration and inlet temperature of water), and design conditions (e.g., different passive/active designs of solar stills, slope of the cover, materials selection, storing materials, reflectors, insulation, gap distance and sun tracking system). It was also determined that the performance of solar stills was improved through the increase in solar radiation, ambient air temperature, wind speed, and water absorptivity. This also rings through with the decrease in water depth, thickness of cover, gap distance between water surface and condensing cover. It was also determined that both internal and external reflectors are capable of increasing the amount of absorbed solar radiation on the basin liner. The potential output of a basin type still can potentially increase to almost 70–100%. On top of this, the utilization of a sun tracking system was determined to be way more effective in improving the performance of solar still. This translate to the fact that solar stills being able to produce potable water at a very economical cost. Due to the existence of different methods of cost estimation, it is not possible to determine a universal, comparable price per technology; the cost per liter of distilled water obtained from the basin type solar still is ranged from 0.035 to 0.074$/liter. This study proved the fact that distillation productivity of solar still is heavily influenced by climatic, operational, and design parameters. Its output can be further improved via operational and design conditions, as climatic conditions are beyond our control.

Contents

1. Introduction . . . 431
2. Parameters affecting basin type solar still productivity. . . . 432
   2.1. Climatic parameters. . . . 432
      2.1.1. Solar radiation . . . 432
      2.1.2. Wind speed . . . 433
      2.1.3. Ambient temperature . . . 433
      2.1.4. Dust and cloud cover. . . . 433
   2.2. Design parameters. . . . 434
      2.2.1. Single- and double-sloped solar stills . . . 434
      2.2.2. Water depth. . . . 434
      2.2.3. Inclination of cover . . . 435
      2.2.4. Type of solar still . . . 436
      2.2.5. Hybrid solar still . . . 438
      2.2.6. Stepped solar still . . . 439
      2.2.7. The selection of the material. . . . 439
      2.2.8. Energy absorption and storing materials . . . 440
      2.2.9. External and internal reflector . . . 440

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2.2.10. Sun tracking system. 441
2.2.11. Insulation thickness 441
2.2.12. Gap distance 441
2.3. Operational parameters 441
2.3.1. Coloring of water 441
2.3.2. Water flow 442
2.3.3. Surfactant additives 442
2.3.4. Salt concentration 442
2.3.5. Other effects. 443
3. Cost analysis 444
4. Conclusion 445
References 445

1. Introduction

The scarcity of fresh water has become a bane of many countries recently. The consumption of drinking water has increased in tandem with the population explosion and rapid industrial expansion, which precipitated a lack of freshwater supply in certain countries. Fresh water represents the core of human life, being vital to many industries that props up our daily lives. However, more often than not, it is polluted by chemical impurities and harmful organisms, and thus, it requires purification prior to consumption. Places where there is an ample supply of both solar radiation and brackish water will allow the production of reasonable amounts of potable water at economical costs via solar stills that are easily constructed and relatively cheap. This concept is also useful in the context of supplying water to rural or far flung communities. The classifications of solar still distillation are given in Fig. 1 [1]. Solar stills are categorized into two distinct types; active and passive. In the case of passive stills, the water in the basin undergoes direct heating, which basically did away with any need for external heating sources and causes the distillation and heat collection to occur within one system. Passive solar stills are divided into conventional and efficient designs. The water in active solar stills undergoes direct heating as well, but it also receives preheated water via an indirect channel that is being heated externally, for example, hot water available from solar collector, heater, and a recirculation of outgoing water in order to increase the water temperature in the basin, which will inevitably increase the evaporation rates. Active solar stills are divided into integrated with solar collecting system, which included (Concentrator collector, Flat plate collector), powered by waste heat and hybrid solar stills. Stills were first used in 1551 by Arab alchemists, and this was followed by its utilization by other scientists and academics, among them Della Porta (1589), Lavoisier (1862), and Mauchot (1869). The first conventional solar still plant was built by Charles Wilson, a Swedish engineer, for a rather obscure mining community in Las Salinas; located in modern day Chile. The early stills were made up of large basins that supplies high-salinity fresh water (4-folds of seawater) derived from nitrate mine effluents to the mineworkers and nearby inhabitants. The early stills are made up of quite a number of designs and materials. The actual amount of water that can be distilled depends on quite a number of factors, among them geographical location, sun position, general meteorological conditions, solar still design, and operational techniques. What makes solar distillation viable is the fact that its operational cost is very low [2]. There are several review papers focusing on R&D of solar still

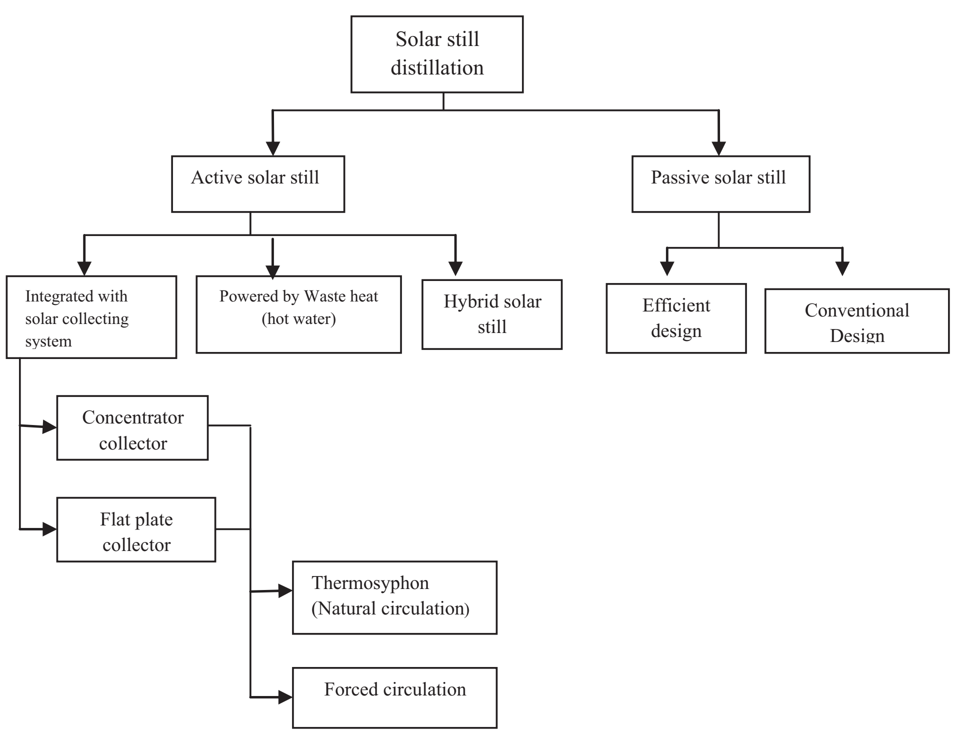


Fig. 1. Classifications of solar still distillation.

systems. Velmurugan and Srithar [3] reviewed certain modifications on the solar still systems and their respective performance enhancement. Aayush Kaushal and Varun [4] evaluated the effect of different designs and methods on solar still productivities. Sampathkumar et al. [5] reviewed different types of active stills, while Kabeel and El-Agouz [6] reviewed single basin type passive stills, with emphasis on performance enhancing modifications.

In this study, a comprehensive detailed review is conducted to investigate the effects of climatic, operational, and design parameters on the performance of existing active/ passive basin type solar still systems.

2. Parameters affecting basin type solar still productivity.

The productivity of a solar still is influenced by three factors; namely ambient, operating, and design conditions, shown in Fig. 2. Ambient conditions include ambient temperature, isolation, and wind velocity, while operating conditions include water depth, various dyes, still orientation, and inlet temperature of water, among others. Moreover, design conditions include covering slope, various solar still designs, and membrane and module designs.

2.1. Climatic parameters

2.1.1. Solar radiation

Solar radiation represents the most vital factor vis-à-vis still productivity. Many researchers have investigated the effect of solar radiation on still productivity, and their results indicate that solar still productivity increases with increasing incident solar radiation [7]. However, Okeke et al. [8] reported that the incident solar radiation heats up liquid, which evaporates them, in turn instigating heat losses. Fig. 3 details the flow of energy in a solar still. The energy transfers that distills water in the setting of a solar still encompasses the supply of evaporating heat and its removal from condensed vapor. Incidentally, the increase of the energy transfer rates increases yield. Morse and Read [9] utilized analytical expressions to determine the effect of different parameters, such as solar radiation, wind velocities, ambient temperatures, and heat

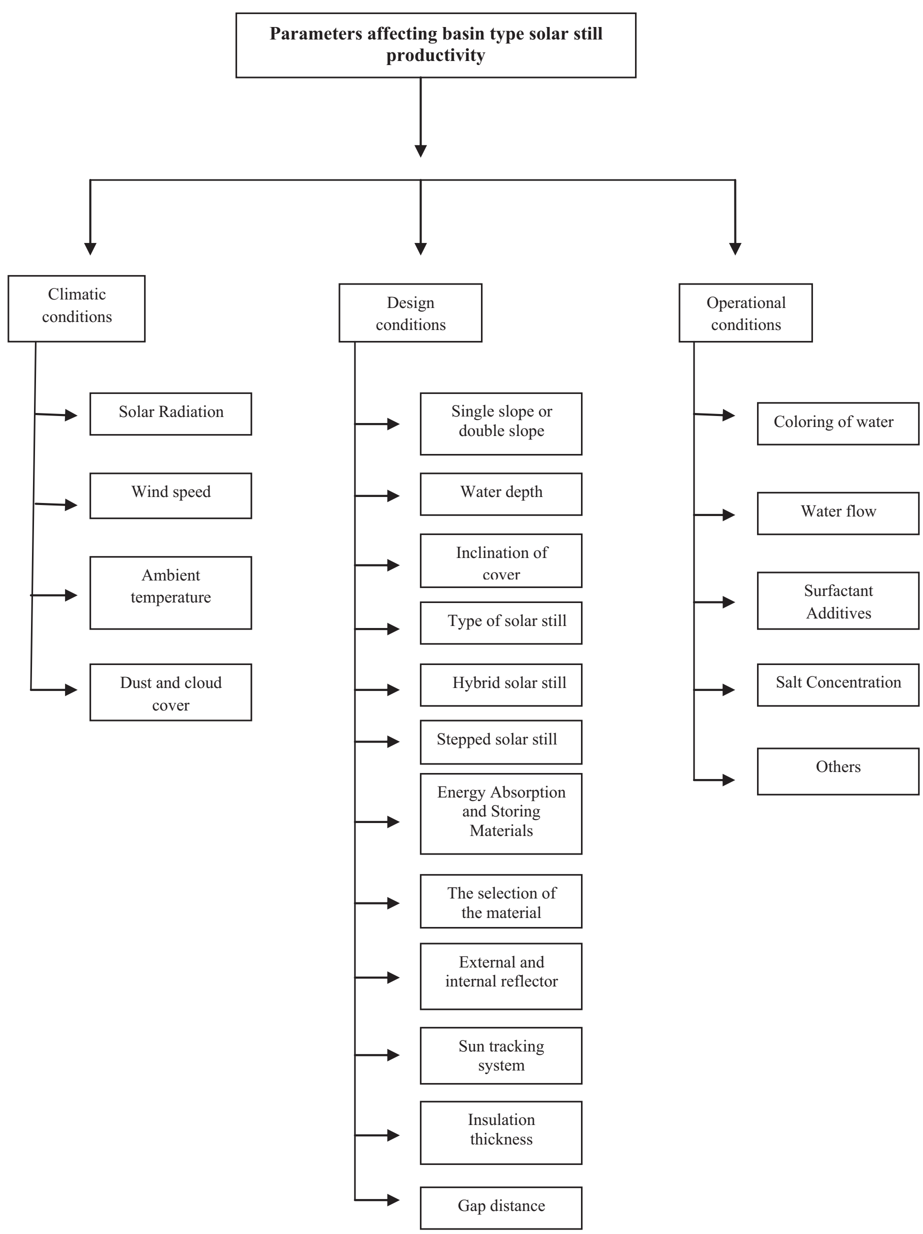


Fig. 2. Parameters affecting basin type solar still productivity.

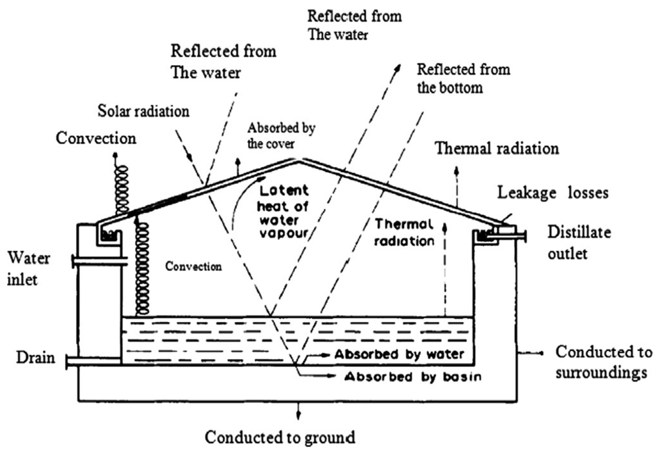


Fig. 3. Schematic diagram of the solar still.

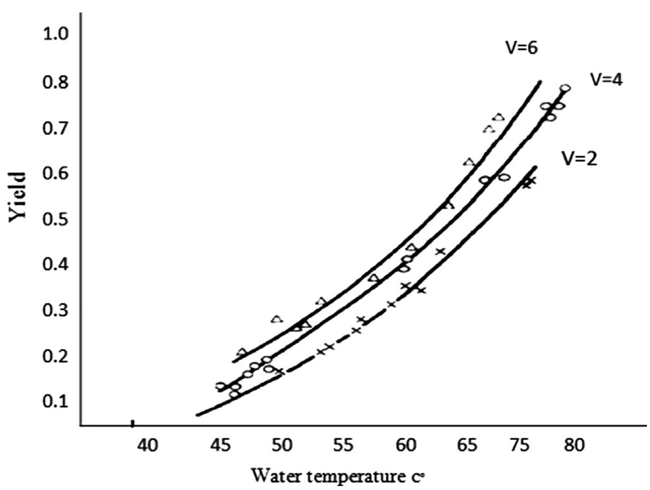


Fig. 4. Variation in yield with water temperature at different wind speeds.

loss changes on the productivity. The results seems to support the idea that solar radiation is absolutely essential to the process. Kamal [10] successfully demonstrated that outputs are very much dependent on the input, which in this case is solar energy. Rahbar and Esfahani [11] reported that solar radiation and ambient temperature have a direct effect on still performance. Aburideh et al. [12] carried out an experiment to examine the effect of climatic conditions on a double-slope plane solar still in the town of Bou Ismail-Algeria, and the results indicated that the increase of productivity strongly relies of incidental solar radiation.

2.1.2. *Wind speed*

The effect of wind speeds is insignificant vis-à-vis productivity. Productivity increases with decreasing cover temperatures. The temperature difference between glass and water widens with decreasing cover temperature, which consequently improved the natural circulation of air mass within the still. Moreover, the convective heat transfer from the cover to the atmosphere increases when both evaporative and convective heat transfers between the basin water increases to compensate for high wind speeds [13–15]. However, Soliman [16] investigated roof-type solar stills under forced convection conditions to determine the effect of wind velocity on the output in detail by integrating heat and mass transfer modes. When the flow is parallel to the inclined surfaces of the cover at multiple wind speeds and at an angle of inclination of 10°, as shown in Fig. 4, the variation in the output against the water temperature increases when the temperature gradient between the water temperature and cover temperature is enhanced. The rate of evaporation increases with increasing wind velocity. El-Sebaii [17] investigated the effect of wind velocity on the outputs of active and multi-effect passive stills, and concluded that the yield increases with increasing wind speed. El-Sebaii [18] analyzed the influence of wind speed on the performance for multiple masses of water in basins, and he concluded that performance improves with increasing wind speeds. However, it was also shown that when the speed of wind increased from 1 to 9 m/s, the total yield of the system fell by 13% [19]. There was also a parallel effort made to analyze the influence of wind velocity on various heat transfer coefficients that are involved in the upward heat flow process for established solar still. The results indicated that for set ambient and water temperatures; the radiative heat transfer coefficient between water and glass (hrwg) decreases with increasing wind speed, second, the wind speed is insignificant vis-à-vis evaporative heat transfer coefficient between water and glass (hewg), and finally, the radiative heat transfer coefficient between glass and sky (hrgs) decreases with increasing wind speeds [20].

2.1.3. *Ambient temperature*

Several researchers have investigated the effect of the variation in ambient temperatures on solar still productivity by using a theoretical model proposed by Malik et al. [21]. The results proved that a minuscule increase in the order of 3% in the performance of solar stills was made possible by an ambient temperature of 5 C°, shown in Fig. 5 [19]. This was also supported by the work of Hinai et al. [22], who pointed out that a rise in the ambient air temperature by 10 °C enhances output by 8.2%.

2.1.4. *Dust and cloud cover*

The influence of the accumulation of dust on glass plates upon solar transmittance with differing tilt angles has been extensively analyzed, and it was concluded that transmittance is strongly correlated to dust accumulation. It was also concluded that the deposition of dust is directly correlated to the tilt angles. As a matter of fact, as the deposition of dust increases, the level of transmittance drops [23]. Hottel and Woertz [24] analyzed the influence of dust accumulation with respect to solar thermal systems. The experiment was performed in Boston, Massachusetts, and the results showed that an average of 1% loss of incident solar radiation was due the glass cover being covered in dust, with a tilt angle of 30°. El-Nashar [25] designed and carried out an experiment to analyze the influence of gathered dust on the productivity of evacuated-tubes in flat-plate type collectors. He reported that glass transmittance fell by 10% during the summer and 6% during the winter. However, it was observed that when left alone and not

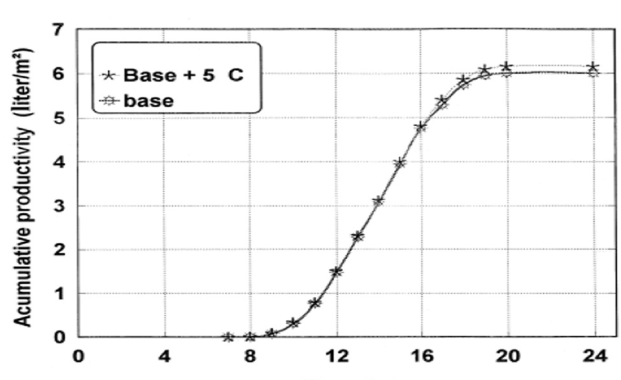


Fig. 5. Accumulated productivity evolution during daytime.

cleaned, the collector exhibited a 70% reduction in its transmittance annually [26]. On the other side, Zamfir, et al. [27] performed an experiment to study the influence of clouds on the monthly averaged performance of a collector. The results showed that during the monthly general days, the performance is inferior to the mean cloudy days.

2.2. Design parameters

Several experimental and numerical investigations on the various design aspects of solar stills were conducted.

2.2.1. Single- and double-sloped solar stills

Garg and Mann [28] conducted experiments to determine the effect of design parameters on the performance of single-and double-sloped solar stills in the arid zones of India. It was discovered that single-sloped solar stills are recipient to higher levels of solar radiation at both low and high latitude stations compared to its double-sloped counterpart. Eduardo et al. [29] built a double-sloped laboratory still setup, with controlled water at different glass cover temperatures, as shown in Fig. 6. Their model was compared with other single-sloped still experimental data, and no significant differences between the productions of the single-and double-sloped cases were observed under similar water and cover temperatures. Rajaseenivasan and Murugavel [30] worked on double-sloped single basin and double-basin solar still, both theoretically and experimentally. In their work, and extra basin was added to the established single-basin for the purpose of increasing the performance of the double-sloped solar still. It was discovered that this addition prompted a productivity increase of almost 85% as compared to its single basin counterpart operating under similar circumstances.

On the other hand, Mamlook and Badran [31] utilized a fuzzy control method to gauge the loads of different essential factors (i.e., design and climate) affecting the performance of a single-basin solar still. They mentioned some of the results of the following studies: first, Naim and Abd El Kawi [32] managed to prove that the usage of charcoal particle beds improved productivity by almost 15% when compared to the wick-type stills; second, Nafey et al. [33] pointed out the utilization of black gravel (as a storage medium) guarantees the quick absorption and release of solar energy as opposed to black rubber. They also came to the conclusion that the using 20–30 mm black gravel will increase the productivity by 19% in 20 L of saline water and glass cover angle of 15°; third, Nijmeh et al. [34] posited that single-slope solar stills can be enhance by 26% via the utilization of potassium dichromate is combined with water to form an absorbing material; fourth, Bilal et al. [35] found out that the performance of single-sloped solar stills can be improved via the utilization of designated rubber materials by 38% in terms of daily water productivity; fifth, Kumar and Tiwari [36] confirmed that water flow over an active glass cover maximizes yield compared to a standalone still; Sixth, Voropoulos et al. [37] analyzed the behavior of solar stills that are integrated with a hot water storage tank. The results of their work proved that integrating the systems could potentially increase outputs. Their work also involved looking into the work of Meukam et al. [38], who experimentally analyzed cover slopes and proved the fact that cover angles at of 16° optimizes solar radiation within the stills and stops distillates from falling into the basin. Finally, Esteban et al. [39] confirmed that the daily output of an integrated solar collector storage unit exceeded both basin-type solar stills (70%) and flat solar collectors (20%).

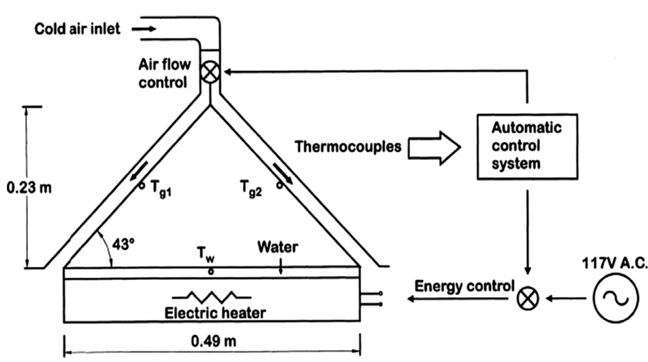


Fig. 6. Automatically controlled double-sloped experimental still.

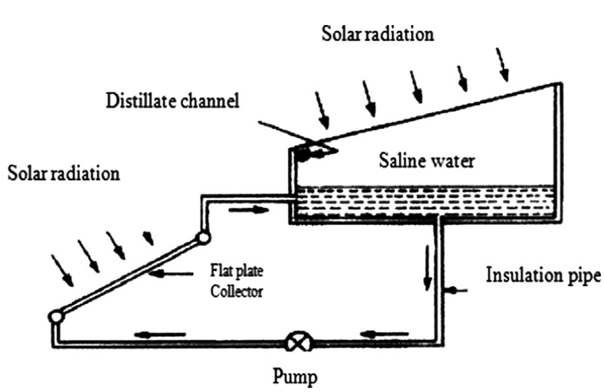


Fig. 7. Schematic diagram of an active solar still, coupled with a flat-plate collector.

2.2.2. Water depth

The depth of the water in the basin is thought to actively influence the performance of a still [40]. Quite a few studies were conducted to confirm this fact, mostly involving design optimization of solar stills via the analysis of water depth in basins. The results positively showed output decrease as the depth of water in the basin increases. Khalifa et al. [41]; Phadatare and Verma [42]; Tiwari and Tiwari [43]; Tripathi and Tiwari [44] attempted to investigate the effects of different water depth basin solar stills on the heat and mass transfer coefficients for the passive and active modes, shown in Fig. 7. The distillate output is known to significantly decrease in tandem with increasing water depth in the basin of the solar still. In the case of an active solar distillation system, more outputs were obtained compared to the passive solar still, due to the high temperature difference between the water and the internal glass cover temperatures in the active mode. The convective heat transfer coefficient between the internal

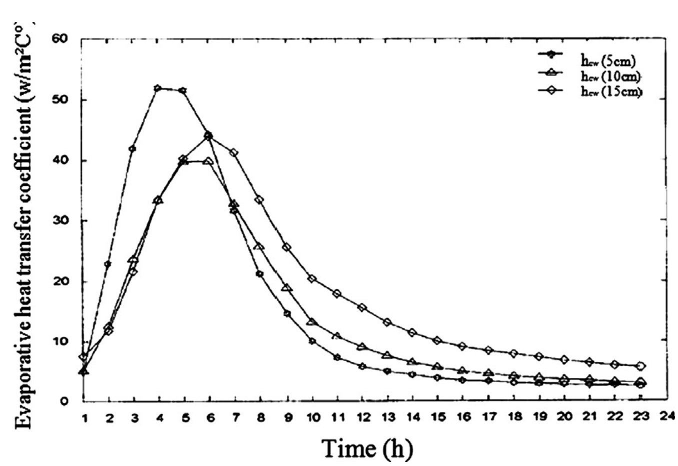


Fig. 8. Hourly variation in evaporative heat transfer coefficient in active mode for different depths.

condensing cover and water significantly depends on the depth of water that is present in the basin, as shown in Fig. 8. Tiwari and Tiwari [45] also initiated a fresh investigation into the influence of water levels on both heat and mass transfer in a passive solar still. The setting of their experiments were a total time of 24 h on five days and water depths, ranging from 0.04 to 0.18 m, facing the south on an inclination of 30° against a condensing cover. Both convective and evaporative heat transfer coefficients are vital towards water depth optimization in terms of obtaining the maximum output during the summer in the case of single-sloped passive solar distillation unit. The highest yield and efficiency were observed at low depths.

The performance of a double basin solar still is highly reliant on the depth of water of the lower basin. At lower water depths, the distillation process improved significantly, but it was almost halted when the sun was absent [46]. Correspondingly, the performance of an inverted absorber of a double basin solar still improved when the water levels in the lower basin increased [47]. It can be concluded that the performance of a solar still is inversely proportional towards water depth, as shown in Table 1 [28].

2.2.3. Inclination of cover

The yield from a solar still heavily relies on the tilt angle of the solar glass. This angle in turn depends on inclination and the direction the cover is facing, and also its latitude. It is expected that covers that has an inclination that is aligned with the angle of the latitude will be the recipient of a normal solar radiation annually. This is deemed as important due to the fact that evaporation is reliant on intensity of solar radiation. This leads to the adjustment of the angle of inclination with respect to the solar azimuth angle and solar intensity [6]. Singh and Tiwari [48] conducted a numerical analysis for latitudes of (13–28°N), taking into account the effect of solar radiation, wind speeds, water depths, and cover tilt angle on productivity. They observed that the optimum glass tilt angle for maximum annual output should be the latitude of the location. A similar study was conducted in India (latitude 28.36°N) by Kumar et al. [49], and based on their numerical analysis, a glass tilt angle of 15° resulted in the best performance. Akash et al. [50] discovered that a 35° glass inclination angle results in the maximum yield in the month of May. The experiments conducted at (latitude 31.57°N) in Jordan by Khalifa and Hamood [51] investigated the effect tilting a cover on the performance of basin solar stills. It was surmised that output could change by almost 63% via tilting the covers alone [52].

Table 1
Effect of water depth (cm) on distilled water output (l/m^2/day) of a single-sloped solar still.
Source: Garg and Mann (1976).

Test no.	Un-insulated still				Insulated still
	2 cm	4 cm	6 cm	8 cm	4 cm
1	2.93	2.95	2.82	2.67	–
2	4.11	4.06	3.87	3.43	–
3	3.77	3.72	3.65	3.31	–
4	3.87	3.50	3.59	3.34	–
5	3.55	3.21	3.28	2.98	–
6	3.59	3.30	3.18	3.08	–
7	3.47	3.24	3.16	3.10	4.21
8	3.11	3.00	2.84	2.63	4.09
9	3.54	3.24	3.22	3.19	4.67
10	2.98	2.70	2.76	2.73	3.87
11	3.02	2.72	2.61	2.27	3.61
12	2.02	1.98	2.00	1.99	3.28
13	3.03	2.78	2.59	2.55	3.81
Average	3.32	3.11	3.04	2.86	3.93

Prasad and Tiwari [53] experimented on a concentrator-assisted solar distillation system, shown in Fig. 9. They analyzed the effect of the inclination of glass covers on the internal heat transfer coefficient, and they found that the daily output increased with inclination, as shown in Fig. 10. In addition, Tiwari and Tiwari [54] attempted to optimize the condensing cover inclination in a passive solar still for a maximum daily yield under winter climatic conditions. The convective mass transfer relations were determined at three different inclinations of condensing cover. Fig. 11 shows a cross-sectional view of the schematic diagram of a single-sloped passive solar still. Under winter climatic conditions, the highest yield was observed at a 45° inclination of condensing cover. Kamal [10] performed experimental and

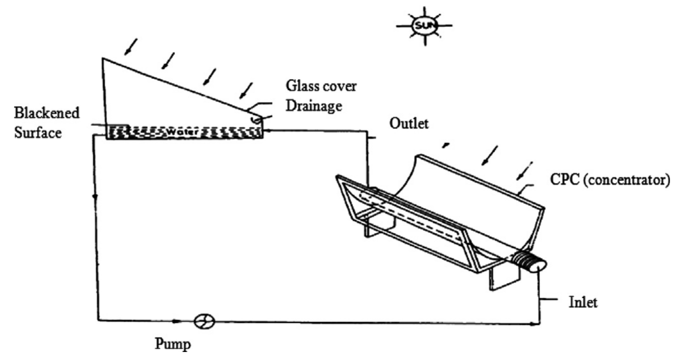


Fig. 9. Cross-sectional view of a concentrator-assisted solar distillation system.

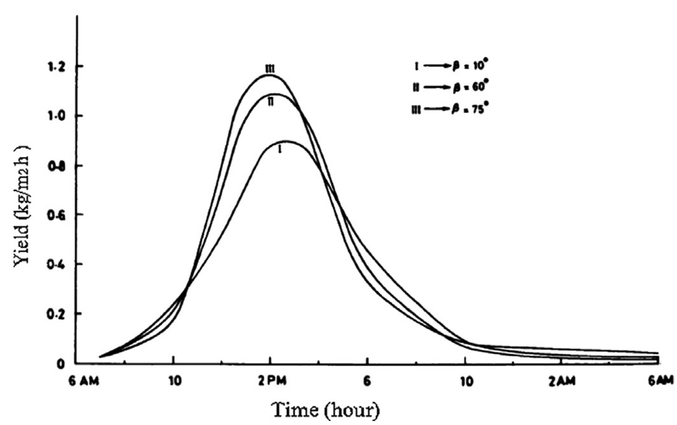


Fig. 10. Effect of inclination hourly yield.

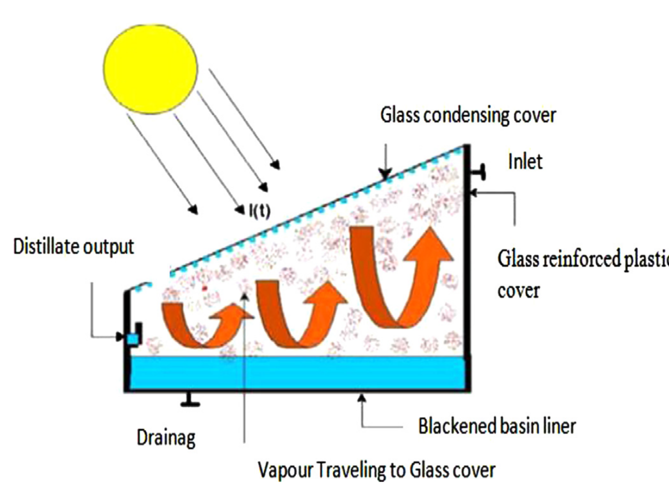


Fig. 11. Cross-sectional view of the schematic arrangement of the experiment.

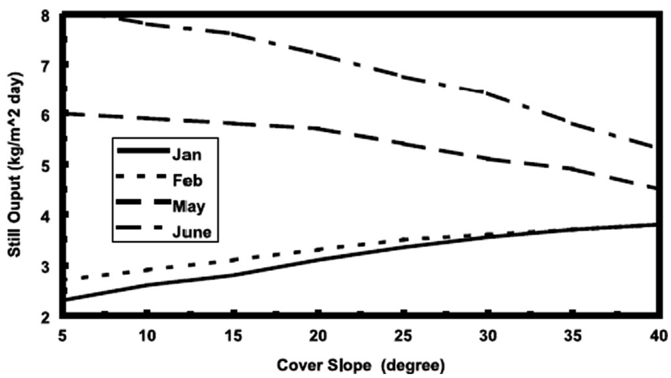


Fig. 12. Effect of cover slope angle on single still output in winter and summer months.

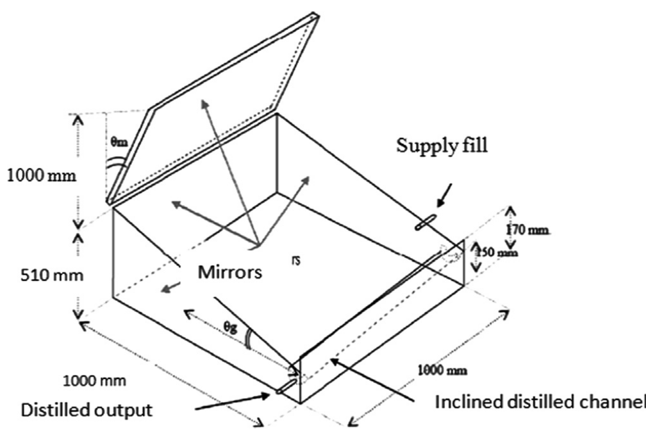


Fig. 13. Schematic diagram of the basin-type solar still.

theoretical analyses on a basin-type solar still under spring climatic conditions in Doha (Qatar), at a latitude of 25.3°N. He recommended a cover tilt angle of 10° for the summer and 15° for the winter to guarantee the production of high quality distilled water. In a similar study, Enein et al. [55] reported that the cover tilt angle should be as low as possible during the summer and 50° during the winter under Egyptian climatic conditions, with latitude of 30.48°N.

Furthermore, Tiwari and Tiwari [56] investigated three solar stills that have its condensing cover tilted in three different angle; 15°, 30°, and 45°. The experiments were conducted in New Delhi (28°37′ N/77°13′ E). Extrapolating experimental data from a clear-day operation proved the fact that keeping water levels minimum and inclining the condensing cover 15° maximizes the annual distillate yield. It was also proven that an angle of inclination of 45 degrees was annually effective, especially during winters. Dev and Tiwari [57] conducted a numerical analysis to analyze the influence of cover tilt angle on both summer and winter under Indian conditions, at a latitude of 28.36°N. They conducted the tests in April, June, and November, and concluded that 45° is the optimum inclination angle for the best performance of a solar still.

Hinai et al. [22] carried out mathematical modeling to foresee the annual performance of a solar still under Omani climatic conditions, at a latitude of 23.36°N. Their numerical results showed that the productivity increased with decreasing glass tilt angles during the summer, while the reverse is true during the winter, as shown in Fig. 12. On the other hand, Khalifa and Ibrahim [58] experimented upon the effects of both internal and external reflectors on a variety of yields for simple basin solar stills in all seasons except spring (tilt angles of 0°, 10°, 20°, and 30°, respectively), and this is shown in Fig. 13. They reported on a simple still with a tilting cover angle of 20° and propped up with both internal and external reflectors at a 33.3°N latitude angle. Hence, a comparable yearly productivity is expected for an external reflector angle that ranges from vertical to 20°.

Karaghouli and Alnaser [59] experimented on single-and double-basin solar stills, as shown in Figs. 14 and 15, respectively. The glass slope angle for the single basin still was maintained at 36° from the horizontal, whereas for the double basin still, it was maintained at 12° from the horizontal. They found that the efficiency of the double basin still was 8% more than its single-basin counterpart.

2.2.4. Type of solar still

Researchers have investigated different types of solar stills, including single basin stills, multiple-effect stills, wick solar stills, and hybrid designs, all in the interest of improving its efficiency. Many experimental and numerical investigations were conducted on different solar still designs. The multi-effect basin still design is made up of multiple basins stacked upon each other. From this configuration, the latent heat of condensation in a basin heats the water in the basin in the immediate basin positioned on top of it, which makes it an effective method in producing desalinated water at reasonable temperatures (mostly under 70 °C) [3]. Fig. 16 shows the tilted-wick still, another type of solar still designed to operate at very low heat capacities [60,61]. The wick solar still is made up of wicks located on a feed tank and one on the inside of the still. Water is led into the still mostly through the wick's capillary action. Yeh and Chen [62] reported that Frick and Sommerfeld [63] came up with a wick type solar still that utilizes a blackened wet jute cloth that forms an amenable liquid surface that prevents the accumulation of high temperatures due to low thermal capacities. However, this is not representative of all three wick-type solar stills, as these solar stills all have different spaces between its respective glass cover and its black jute surface. The output can be increased via a variety of measures, such as cutting

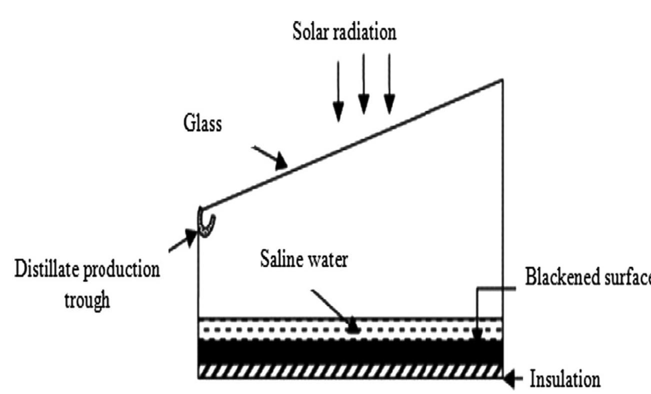


Fig. 14. Single basin solar still.

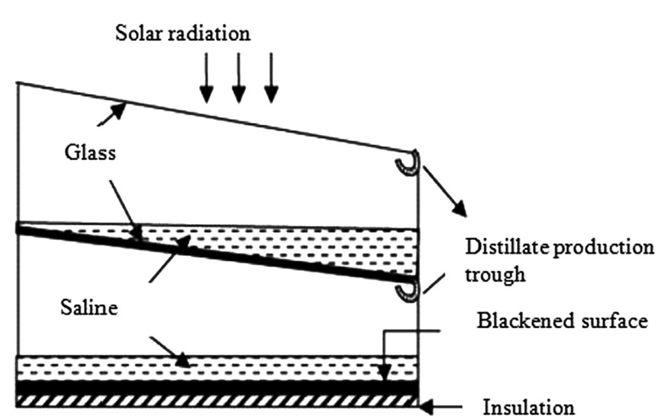


Fig. 15. Double basin solar still.

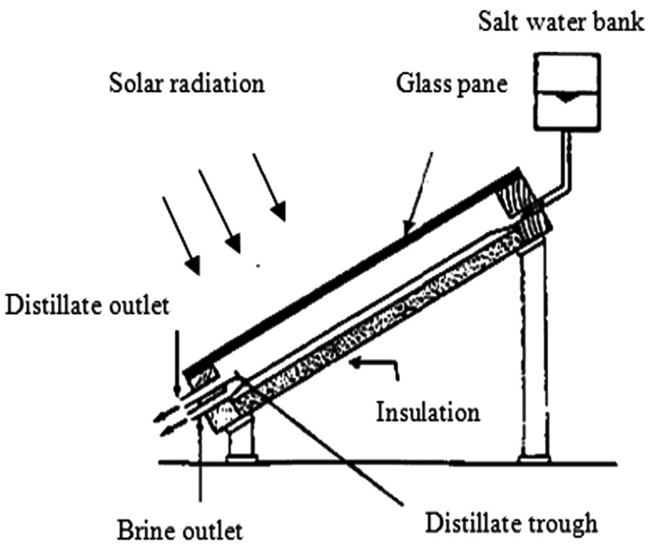


Fig. 16. Tilted wick solar still.



Fig. 17. The experimental still.

down on the pressure on the stills or by constantly removing water vapor using air flows.

Janarthanan et al. [64] considered a new design for the floating-cum-tilted wick type solar still, shown in Fig. 17. The transient performance was determined by integrating the influence of both water mass flow rates and water flow on the glass cover that's caused by the capillary action of the wick, its climatic parameters, and its absorptivity. This theory was duly developed via experimentation on a day in March 2004, in Sri Ramakrishna Mission Vidyalaya, India, and the results are shown in Fig. 18.

Al-Hayek and Badran [2] developed a hybrid design for the instated greenhouse type to analyze the production of fresh water via distillation through two different stills asymmetrical greenhouse type (ASGHT) with mirrors and symmetrical greenhouse type (SGHT) under climatic conditions of Jordan, shown in Fig. 19. The results favor ASGHT over SGHT; as it enhances efficiency via the control of two factors; radiation losses from basins, and incident sunrays on the stills.

Fath and Elsherbiny [65] analyzed the effect of integrating passive condenser on the performance of a single-sloped solar still. Fig. 20 shows the proposed passive condenser connected to the still in the shaded zone of a single-sloped still. Compared to the still without a condenser, the yield increased to approximately 70% when a condenser was used. In another study, the still having a reflector was compared to that without a reflector, and the increase in productivity ratio was 19.9% on average. Moreover, stills having both internal and inclined external reflectors (0°, 10°, 20°, and 30°) generated productivity ratios of 34.5%, 34.4%, 34.8%, and 24.7%, respectively [66]. El-Bahi and Inan [67] investigated the basin-type still with external reflector under the weather conditions in Turkey. They used an external

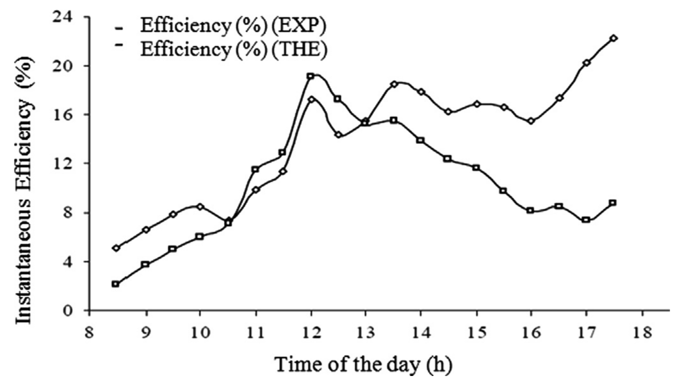


Fig. 18. Instantaneous variations in the experimental and theoretical efficiencies of the still.

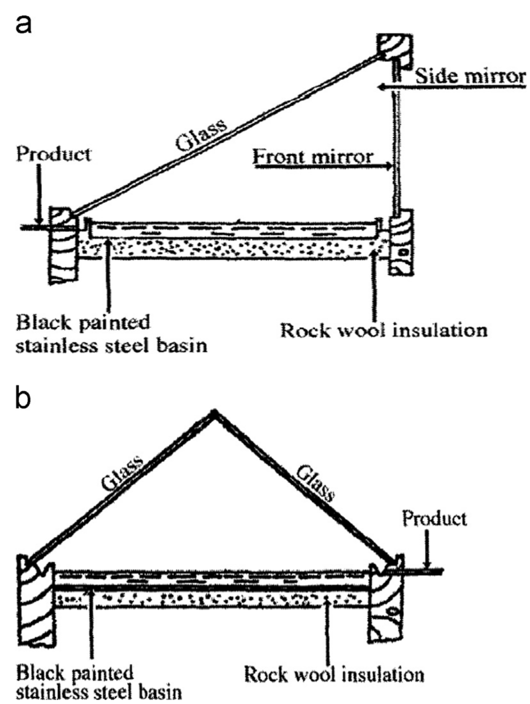


Fig. 19. (a) Schematic diagram of the asymmetrical greenhouse type solar still. (b) Schematic diagram of the asymmetrical greenhouse type solar still.

reflector to increase the incident solar radiation on the glass cover to create condenser shadows.

Moreover, they posited that an external reflector could maintain a higher reflectivity than an internal one.

Moreover, Boukar and Harmim [68] compared an uncoupled simple basin solar still and a coupled still with flat plate solar collector, and managed to prove that the productivity of both stills is heavily reliant on both solar radiation and ambient temperatures. They also noted the fact that the level of productivity was almost doubled in the case of a coupled solar still.

Badran and Tahaineh [69] experimentally investigated the operation of a solar distillation system coupled with solar collector. They compared the outputs of coupled and stand-alone stills, with the productivity of the coupled still being 36% higher than its stand-alone counterpart. This leads us to believe that the current design will lead to increased outputs due to its relatively higher basin water temperature. Moreover, Dimri et al. [70] found that the inner glass temperature is vital in the determination of the yield. Daily yields were better in active distillation compared to passive modes with inner glass temperature. The levels of productivity was proportional to the thermal conductivity of the condensing cover materials, where copper

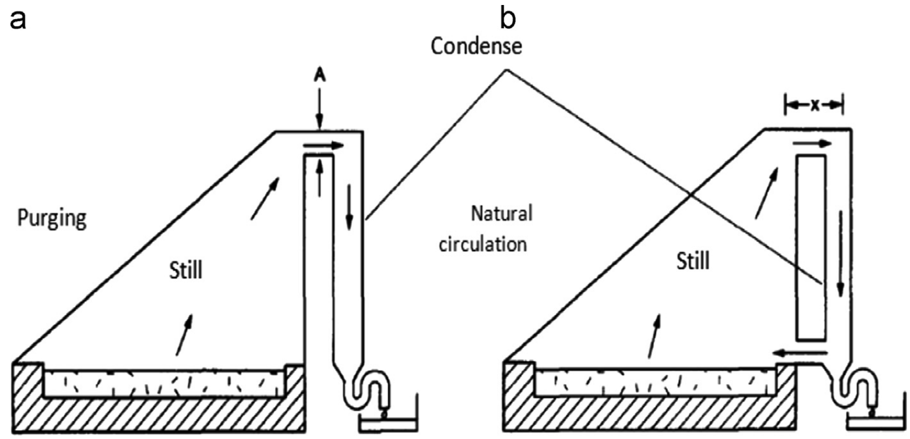


Fig. 20. Solar still with passive condenser.

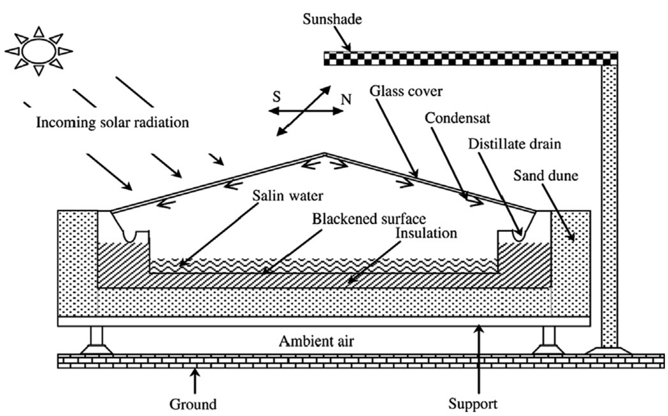


Fig. 21. Cross-section of solar still.

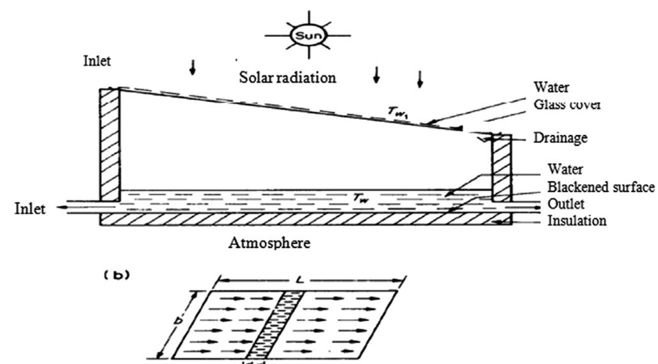


Fig. 22. Schematic representation of the single basin solar still with water flowing over the glass cover and inside the basin. (b) Side view of the flowing water system.

was determined to be superior to both glass and plastic in terms of thermal conductivity, hence resulting in higher levels of output in the case of copper. Another way to realize higher efficiencies is to reduce the loss of heat from sides and base of the stills via insulation. Bechki et al. [71] investigated the effect of partial intermittent shading on the performance of a simple basin solar still. Their experiment was conducted in the city of Ouargla, South of Algeria. Fig. 21 details the experimental setup. Their results confirmed that intermittent shading of the north glass cover of the solar still increase daily yields by 12%.

Fig. 22 shows an analysis of a single basin solar still with intermittent flow of excess hot water through the basin by Tiwari et al. [72]. They utilized a typical day of Delhi as a basis for their calculation, and concluded that yield will be superior when the sunshine exposure was at a minimum as opposed to continuously running water at lower temperatures. However, a continuous flow of water was better than excess hot water flow at high water temperatures.

Badran (2001) [73] conducted an experiment to investigate the effect of integrating a heat exchanger inside the condenser of an inverted trickle solar still. The tests were conducted in May with and without heat recovery back to back for two days. This was done in order to keep the radiation and flow rates fairly constant. Another round of testing was carried out in July to match the flow rates in May, while another round of testing was carried out in November, however this time; it was at different flow rates. It was proven here that heat recovery was somewhat beneficial to the yield of an inverted trickle solar still.

Kwatra [74] investigated the effect of increased water evaporation area on the performance of a solar still via computer simulations. The calculations tried to find a correlation between evaporation area and productivity. The result of the study showed that the gain increase by about 19.6% when the evaporation area was quadrupled, with this being shown in Fig. 23.

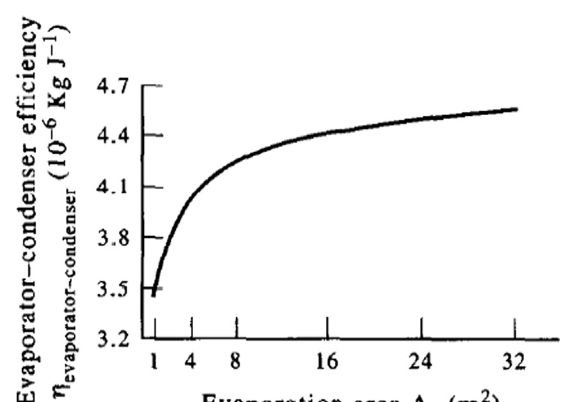


Fig. 23. Performance of the evaporator–condenser. Efficiency is defined in terms of water distilled per unit exergy used.

2.2.5. Hybrid solar still

The hybrid solar stills are unconventional solar stills that incorporate the utilization of external attachments to the still for the purpose of improving the distillation process. It is capable of simultaneously produce distilled and hot water. Voropoulos et al. [75] conducted an experimental investigation of a hybrid solar still coupled with solar collectors, shown in Fig. 24. The results showed

that the productivity of the coupled system is two times more than its conventional counterpart. Voropoulos et al. [76] studied the energy behavior of a conventional greenhouse-type solar still, coupled with hot water storage tank and heated by a solar collector. The results are indicative of the fact that the method might be a perfect optimization and enhancement tool. Furthermore, Voropoulos et al. [77] observed that the productivity of a conventional greenhouse-type solar still coupled with a hot water system was significantly enhanced relative to a conventional solar still. Omara et al. [78] conducted an experiment using a new hybrid system, which included the evacuated solar water heater, wicks still, and solar still, as shown in Fig. 25. An evacuated solar water heater is incorporated into the desalination stills for the purpose of evaluating the continuity output. The productivity increases by about 114%. Bacha et al. [79] modeled a hybrid system to estimate the performance of a system under stipulated climates, allowing the choice of the suitable design solutions vis-à-vis applications. Sampathkumar and Senthilkumar [80] conducted an experimental investigation of solar stills that are integrated with evacuated tube collector type solar water heaters. It was determined that the yield increase twofold. Tabrizi and Sharak [81] carried out an experimental investigation on an integrated basin solar still, with a built-in sandy heat reservoir integrated into it. It was observed that coupling a sandy heat reservoir to a basin solar still enhances it. Gaur and Tiwari [82] attempted to optimize the number of collectors for a hybrid active solar still so that they can maximize the daily output, which lead them to the conclusion that the best amount of collectors must increase in tandem with the mass of water in the basin of the hybrid active solar still.

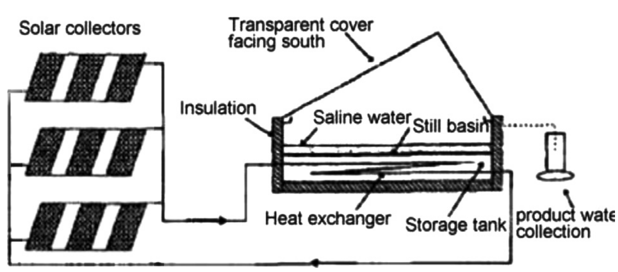


Fig. 24. Schematic diagram of hybrid solar distillation system.

2.2.6. Stepped solar still

It is difficult maintaining a minimum depth in a conventional basin type solar still, as its area is quite large. However, in an attempt to increase production per unit area by decreasing the thermal inertia of the water mass, a stepped solar still is used, where the area of the basin is minimized via the utilization of small trays. Velmurugan et al. [83, 84] designed and analyzed a stepped still. Output increase by almost 98% when the basin was filled with fins and pebbles. Velmurugan et al. [85] analyzed the increase of saltwater streams in solar stills integrated with a mini solar pond. A production rate of 100% was made possible by the installation of basin type solar still that is filled with fins, pebbles and sponges. When solar pond, basin type stepped solar still, and a single basin solar still are connected in series, the productivity reaches 80% if fins and sponges are utilized in both solar stills. Similarly, when the solar pond, stepped solar still, and wick type solar still are connected in series, the maximum productivity reached 78%, which is made possible by the integration of both fins and sponges in the stepped solar still. Furthermore, Kabeel et al. [86] investigated the performance of stepped solar still using trays having different depths and widths. The results showed that the yield is strongly correlated to both factors.

2.2.7. The selection of the material

The research and development done so far has yielded additional useful information on the materials of solar stills. The still cover, being one of the most important components, should have its constituent material carefully vetted. Among the possible choices are glass and plastic. Glass is preferred, but plastics are cheaper. Cover plates serves as a medium for heat transfer, although factors such as thickness and thermal conductivities play a major role in its function. The results showed that a solar still, with a glass cover plate 3 mm thick, increases production rate by 16.5% compared to a 6 mm thick glass cover [87]. The basin liner material must be capable of absorbing solar radiation, and must also be watertight. This material should be capable of resisting high temperatures, because a still may run dry, and Asphalt mats seems to be the most logical choice in lining basin steel. For shallow basins, black butyl rubber and polyethylene sheets are favored. Black butyl rubber has been used, due to its capability to withstand high temperatures. Badran [88] studied the effect of

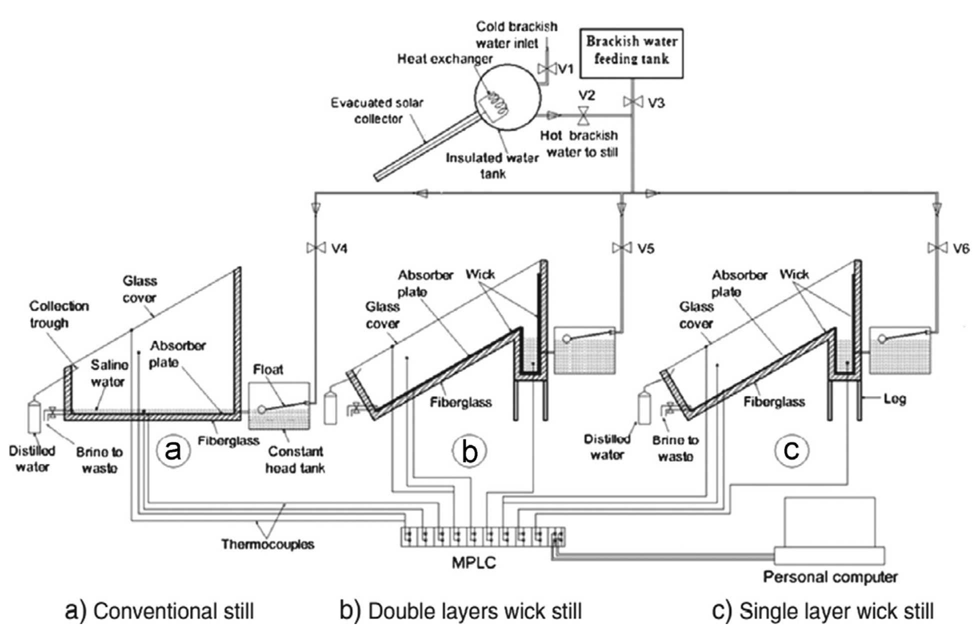


Fig. 25. Schematic diagram of a new hybrid solar distillation system.

using different enhancers, such as asphalt in single solar slope stills. It is showed that a significant increase (29%) was achieved in still productivity when asphalt was used. In order to avoid vapor leakage, it is vital that a transparent cover be properly sealed. Silicon rubber seems to be most effective, due to the fact that it remains elastic for long periods of time. Other sealants are possibilities as well, such as tars and tapes. However, these materials degrade over time, which causes it to crack and permits leakage. The utilization of galvanized iron as a distillate channel is not recommended as it is prone to corrosion when exposed to saline. Aluminum may be used as distillate channel; however, it also corrodes at high temperatures has a similar problem at high temperatures [89].

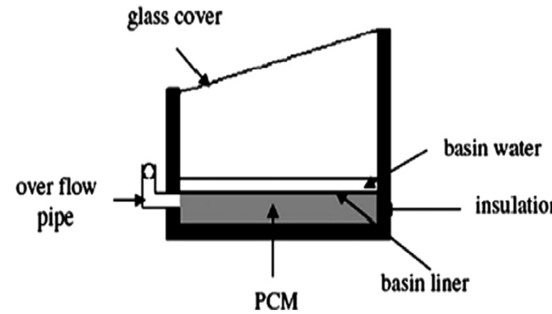


Fig. 27. Schematic diagram of the single slope-single basin solar still.

2.2.8. Energy absorption and storing materials

There are many ways to increase the incident solar radiation, such as by increasing the absorptivity of the solar still (e.g., the addition of charcoal and coal to water increases the energy supplied for evaporation by increasing the solar radiation absorbed in the water), which will result in the increases of absorptivity and reduces heat losses [90]. The addition of absorbing materials contributes to the improvement of the thermal performance of the solar still by increasing the overall water collection. The black rocks were found to absorb incident solar energy better than both coated and uncoated metallic wiry sponges, and enhances the output by almost 20%, as shown in Fig. 26 [91]. Sakthivel and Shanmugasundaram [92] obtained similar results by conducting an experiment on a single-basin solar still that is modified with an energy storage medium of black granite gravel. The still output was found to increase by 17–20%. Rajaseenivasan et al. [93] conducted experiments to increase the productivity of a solar still by adding a basin to the double slope solar still and using mild steel as a storage material, which ended up increasing the output. Murugavel and Srithar [94] tested a basin type double slope solar still equipped with different wick materials, such as light cotton cloth, coir mate, sponge sheet, and waste cotton pieces in the basin. It was discovered that stills with Aluminum fins covered with cotton cloth is more effective. A single basin double slope passive type solar still is tested in a layer of water (approximately 2 mm depth) under controlled input conditions. Murugavel et al. [95] gauged the performance of the still with basin with various spreader materials, such as cotton cloth, a sponge sheet, and jute cloth, and also porous materials such as quartzite rock and washed natural rock. The results confirmed that the black light cotton cloth was more productive. Srivastava and Agrawal [96] experimented on the performance of the proposed modified still with porous fins. The results showed that modified stills results in better performance, with the maximum distillate productivity standing at about 7.5 kg/m².

On the other hand, storage systems can improve the productivity of solar stills, being applicable for latent heat systems.

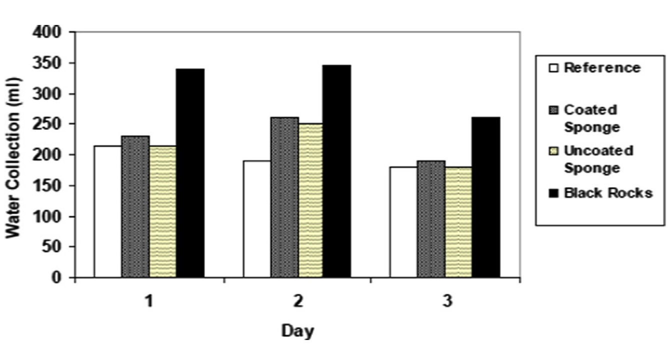


Fig. 26. Water collection for the four solar stills, with and without porous materials, over three days.

This method relies on heat being release from the bottom of stills [97]. The use of phase change material (PCM) as storage media in solar stills is gaining more and more traction. Radhwan [98] analyzed a transient performance of a steeped solar still with built-in latent heat thermal energy storage for heating and humidification of an agricultural green house. During the course of this work, he also investigated the influence of thickness of paraffin wax should it stand in as a PCM and also the mass flow rate of air on the system's performance. The results seem to indicate that a drop in the airflow rate profoundly affects the yield. The total productivity is gauged to be about 4.6 L/m^2, having an efficiency rate of 57%. A transient mathematical model for a single slope-single basin solar still with or without phase change material (PCM) below the basin liner of the still (Fig. 27) was presented by El-Sebaii et al. [99]. Numerical calculations were done with stearic acid representing PCM on typical summer and winter days. Results are indicative of the fact that productivity is directly proportional to the mass of PCM, and this is thought to be due to the heat stored within PCMs. When the PCM is being discharged, the convective heat transfer from the liner to the water in a basin more than doubled. This basically translate to the evaporative heat transfer coefficient increasing by 27% on 3.3 cm stearic acid below at the basin liner. This means that on a normal summer day, the productivity is 9.005 L/m²/day, with a daily efficiency of 85.3%, compared to a productivity of 4.998 L/m²/day when the still lacks a PCM. Incidentally, PCMs are more efficient for lower masses of water during the winters.

2.2.9. External and internal reflector

The addition of internal or external reflectors might be very beneficial vis-à-vis solar radiation on basin liner, which will inevitably translate into better productivities. The work of Tanaka and Nakatake [100] discussed the effect of reflectors on the absorbed solar radiation on a basin liner and outputs at 30°N latitude. They found that distillate output increased by about 48% when reflectors (internal and external) are added. Tanaka [101] theoretically analyzed the basin type solar still using a flat plate external bottom reflector, extending from the front wall of the still to all the way to the internal (two sides and back walls) reflector. The distillate productivity of stills with internal and external bottom reflectors are predicted to be 41%, 25% and 62% more than that of a regular solar still during all seasons except autumn. Khalifa and Ibrahim [102] investigated the effect of internal and external reflectors inclined at angles of 0° (vertical), 10°, 20° and 30° on the productivity of basin solar stills during autumn, summer, and winter. The average daily yield was determined to have increased with the notable exception of the summers, where the reflectors are inversely proportional to the yield. Tanaka [103] conducted outdoor experiments on a basin type still with internal and external reflectors during the winter in Kurume, Japan. It

was inferred that the additions of reflectors will nicrease output to 70–100%. Abdallah et al. [104] suggested the installation of internal reflecting mirrors in single slope solar still, as shown Fig. 28. They found that the productivity increased by about of 30% compared with a traditional solar still.

2.2.10. Sun tracking system

A sun-tracking device was used to keep track of sun movements in the sky and adjust the solar stills accordingly. Some researchers used sun-tracking systems to improve productivity. Ibrahim [105] investigated a collector that is made up of six parabolic troughs with trackers, while Kalogirou [106] described a tracking system that can be used with single-axis solar concentrating systems. Abdallah, and Badran [107] compared and contrasted fixed and sun-tracked stills. Khalifa and Al-Mutwalli [108] investigated the effect of using two-axes sun tracking system on the thermal performance of compound parabolic concentrators CPC, with the CPC determined to be better performance. Abdallah and Nijmeh [109] used a two-axes sun tracking system with a PLC control to gauge the performance of photovoltaic panels (PV), and concluded that the integration of a sun tracking system was very beneficial to productivity, increasing it by almost 50%. Abdallah et al. [104] aimed to improve the performance of the single slope solar still by replacing the flat basin with a step-wise basin and mounting the traditional solar still with a sun-tracking device. The improvement of productivity via this system was immense, reaching a value of 380%.

2.2.11. Insulation thickness

Moreover, Khalifa and Hamood [51] investigated the effect of insulation thickness on the productivity of basin solar stills. Solar stills with insulation thicknesses of 30, 60, and 100 mm were examined, and the results were compared stills lacking insulations. It was determined that insulation thickness plays a major role up to a point, where it is 60 mm thick and increased the output to 80%. This is thought to be due to the increased operating temperature that was caused by insulation. Karaghouli et al. [59] conducted an experiment on single-and double-basin solar stills to investigate the influence of side insulation on the distillate outputs, and he found out that having side insulation was greatly beneficial, especially for double-basin type. The efficiency increased by 2–4% when the sides of the single-basin still was insulated, but the effect tripled for an insulated double basin. Hinai et al. [22] modeled the annual performance of a solar still in Oman, at a latitude of 23.36°N. They reported an optimum insulation thickness of 0.09–0.13 m. Basically, their results confirmed the fact that insulation thickness is directly proportional to still productivity.

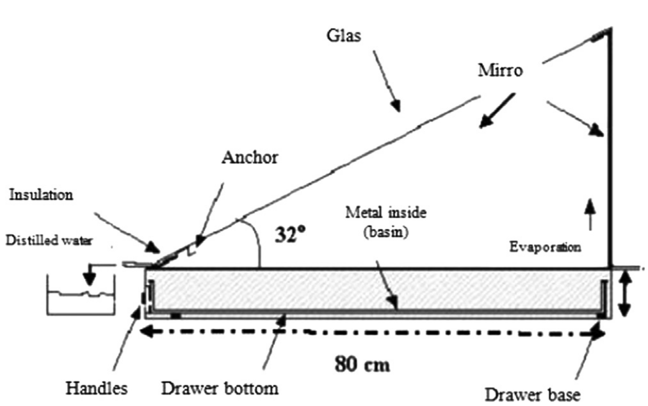


Fig. 28. Solar still with internal reflecting mirror.

2.2.12. Gap distance

There is a gap between the surface of the water and a condensing cover in the still system, and reducing this gap will increase the performance of the stills. It is also speculated that the influence of the distance of the gap is profoundly more significant compared to the influence of cover tilt angle. [40]. Ghoneyem [40] put this improvement in numbers; in his work, he reduced the gap between water surface and cover from 13.0 cm to 8 cm, which resulted in an increase of 11% in terms of daily productivities.

2.3. Operational parameters

2.3.1. Coloring of water

In a conventional still, the base absorbs a large amount of solar radiation, rendering it to be the hottest area of the still. Heat is transferred from the bottom surface to the water via convection, and to the outside atmosphere via conduction through the insulating layer. The mixing of dye with water will cause it to absorb almost all solar radiation, and the water will then transport heat right to the bottom, which will then be passed to the surroundings via the insulation [110, 111]. Rajvanshi [112] experimented with water-soluble dyes in two deep basin solar distillation units having similar depths, which were specifically constructed for the test. One unit was for control, while the other for testing dyes. His results confirmed it; the productivity of the stills increased by 29%, with the black napthylamine dye found to be the best for both the fastness of light and increasing evaporation, as shown in Fig. 29.

Pandey [113] carried out the same experiment, but for a double-basin solar still. Dye was mixed with water in the lower basin. In short, he confirmed that the output of the system was increased, probably due to the dye. However, Bassam and

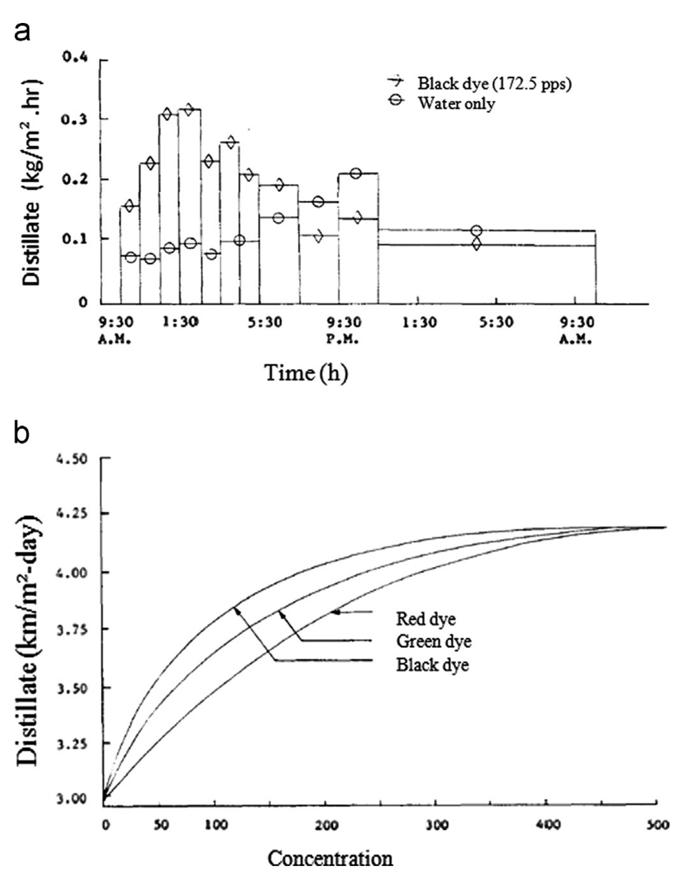


Fig. 29. (a) Distillate histograms of two stills. (b) Analytical plot of the effect of dye concentration on distillate output.

Abu-Hijeh [114] discovered that the utilization of dye is negligible vis-à-vis efficiency if convection between the basin and the surroundings were absent. Therefore, the still's efficiency is enhanced without having to worry about the health risks of using dye to produce distilled drinking water.

2.3.2. Water flow

The productivity of a solar still depends on the temperature gradient between water and the glass cover. The temperature gradient acts as the driving force for the distillation process [3]. It is assumed that yield and heat transfer coefficient is directly proportional to each other in this case [115]. Suneja and Tiwari [116] used numerical analysis to estimate the coefficients of the internal heat transfer of an inverted absorber solar still with water flow on the condensing cover. It was surmised that the evaporative heat transfer coefficient is inversely proportional to water depth, while evaporative heat loss is assumed to have a directly proportional relationship with the operating temperatures. Bapeshwar and Tiwari [117] investigated the effect of water flow over the glass cover on the performance of a single basin solar still, and concluded that its performance was superior.

Lawrence et al. [118] studied passive conventional solar stills and the effect of water flow over the glass cover. Fig. 30 details the study suggested by Tiwari and Rao [119]. An experiment was conducted using fiber reinforced plastic (FRP) solar still at the University of Papua New Guinea, and it was concluded that flow rate and the efficiency of solar stills are directly proportional.

Mahdi et al. [120] performed indoor and outdoor experimental tests to determine the correlation between input water flow rates and productivity. They designed and constructed the tilted wick-type solar still (Fig. 31). They concluded that water mass flow rates and efficiency is inversely proportional in the case of a wick-type solar still. Tabrizi et al. [121] designed a cascade solar still to study the influence of water flow rates on the internal heat and mass transfer and daily distillate output of cascade solar still. The results were conclusive of the fact that internal heat and mass transfers and daily yield are inversely proportional to water flow rates.

2.3.3. Surfactant additives

Surfactants are specialized additives used for transforming the surface properties of water, as they reduce surface stress and enhance boiling heat transfer and skin friction in tubes [122]. Nafey et al. [123] presented a solar distillation system compound that is made up of a flat plate solar collector and a flash evaporation unit to investigate the effect of surfactant additives on daily productivity. Their results prove that the yield increased by 0.7%, 2.5%, 4.7%, and 7% at additive concentrations of 50, 100, 200, and 300 ppm, respectively, as shown in Fig. 32. Moreover, their results confirm that the water distillation process can be enhanced via surfactant additives.

2.3.4. Salt concentration

The fact that salt concentration effects still's productivity has been duly analyzed by Baibutaev [124]. The study showed that as the salt concentration of the water to be distilled increases right up to the saturation point, the productivity of the still slowly declines at a set linear rate. Moreover, as the salt concentration of the water to be distilled increases, there is an increase in the corrosion damage to the components of the still. Kalbasi and

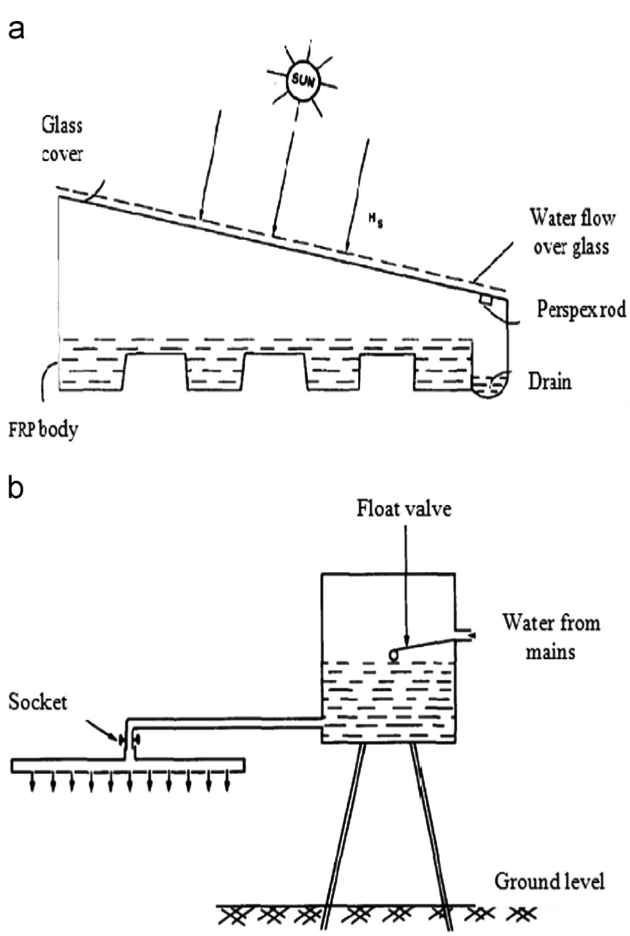


Fig. 30. (a) Cross-sectional view of the solar still. (b) Experimental setup of water flow over the glass cover.

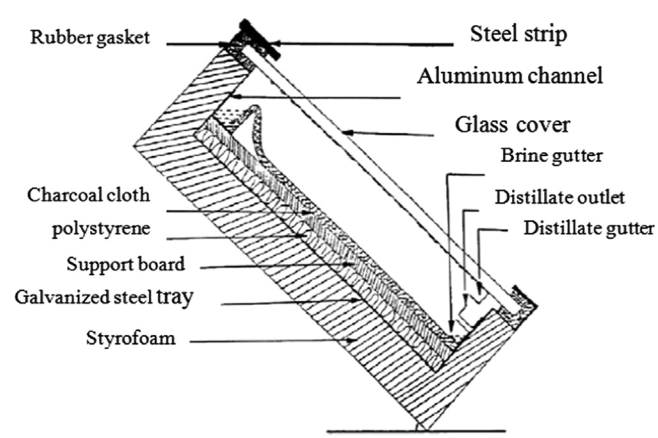


Fig. 31. Cross-sectional view of solar still.

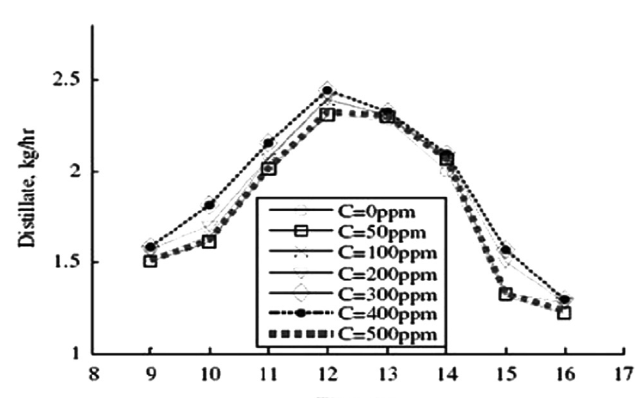


Fig. 32. Variation in distillate product according to variation in surfactant concentration.

Esfahan [125] varied the salt concentration of the water in the basin by systematically adding more salt. The results proved an inverse relationship between daily production and salt concentrations. Increase in the water salinity from 0% to 3.5% results in a 20% decrease in the output. Akash et al. [50] conducted an experiment to investigate the effect of salt concentration on the productivity of a still, and they noticed that when the concentration is high, it results in a smaller decrease in productivity.

2.3.5. Other effects

Some other effects include the total amount of covers, where the number of transparent covers used in a solar still does not increase the yield due to the fact that the inside temperature is the one increasing. Moreover, 25–35% of double glass cover reduction was noticed in the output. The use of double glass cover adds to the total cost of the stills [87].

Ali [126] conducted an experiment to investigate the effect of forced convection inside a convectional solar still. When convection is allowed within the mixture and the fans, the output of the system increased by almost 30%. Fig. 33 shows the experimentally-and-theoretically determined productivities of the solar still during the daily hours of forced and natural convection cases.

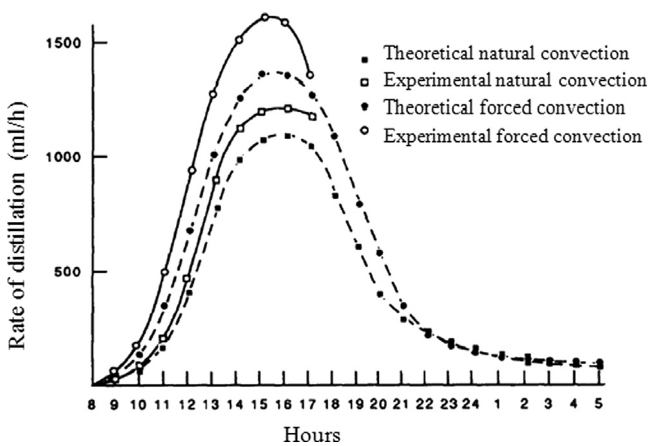


Fig. 33. Water distillations throughout the day.

Yadav [127,128] investigated the performance of a solar still coupled with a flat plate collector using thermosiphon and forced circulation modes in New Delhi climate. Fig. 34 details the schematics used in this work, and it was rather obvious that the performance of the forced circulation mode was superior, as shown in Fig. 35 [129].

Tsilingiris [130] and Pandey [131] pointed out that despite the fact that the usage of dry air leading to overestimation of the coefficient of heat transfer, at higher operating temperatures, these errors were more or less mitigated, where it hovers at around 10% when compared to saturated mixture properties. Additionally, transferring water molecules from brackish water is

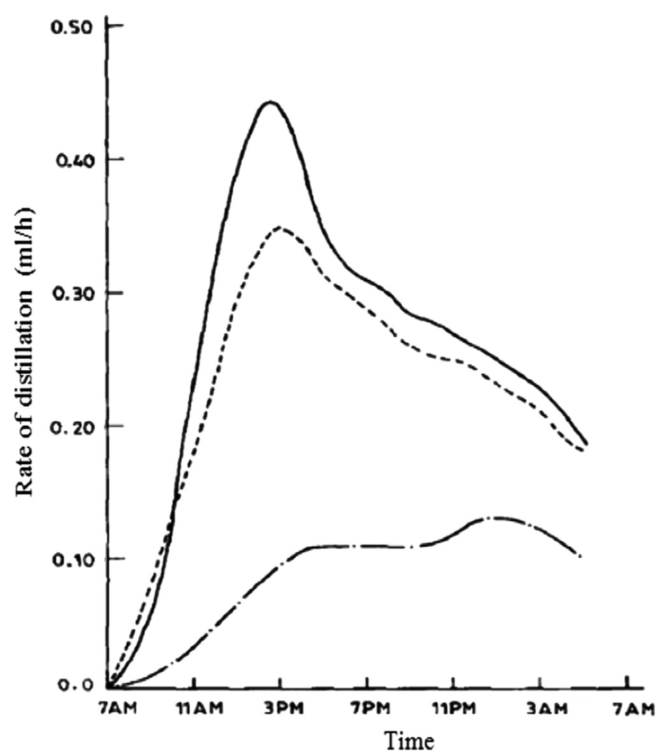


Fig. 35. Hourly variation in distillate output. (-. -) Uncoupled; (- - -) Coupled in thermosiphon mode; (-) Coupled in forced circulation mode.

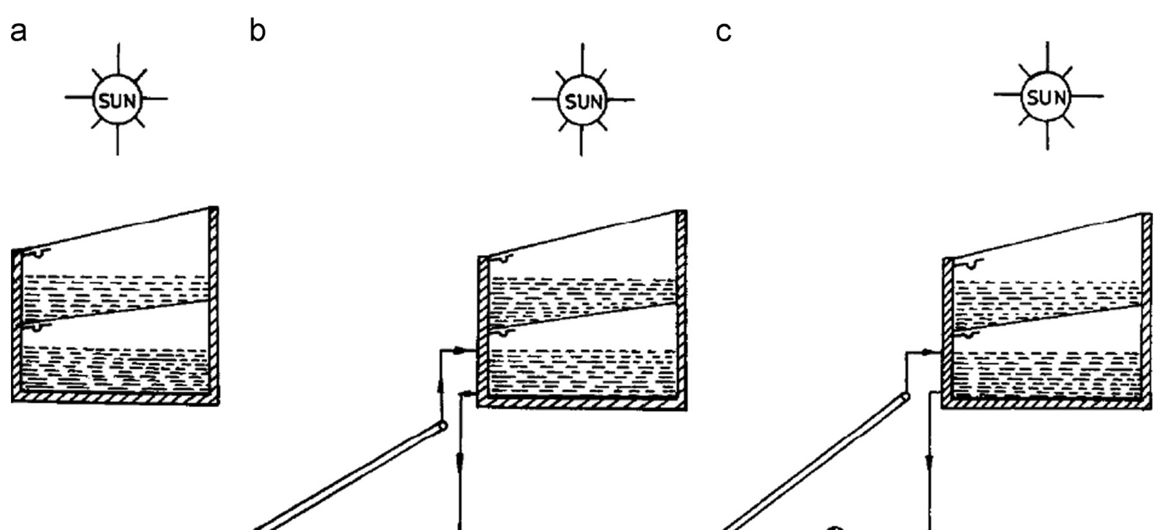


Fig. 34. Schematic diagrams of (a) uncoupled double-basin solar still, (b) double-basin solar still coupled with collector in the thermosiphon mode, and (c) double-basin solar still coupled with collector in the forced circulation mode.

Table 2
Summary of results/conclusions of climatic-design-operational parameters affecting basin type solar still system.

Parameters	Factors	Results/conclusion
Climatic parameters	**Solar radiation** [15–19, 97, 41, 118, 124]	The productivity of the solar still increases with increasing incident solar radiation
	Wind speed [10–12, 96, 18, 110]	The productivity of solar stills increases with increasing wind speed.
	Ambient temperature [45]	A slight increase in the solar still productivity was obtained by increasing the ambient temperature
	Dust [23–27]	Dust deposition increases, transmittance reduction increases
Design parameters	**Single slope/double slope** [20–23, 4, 7, 9, 24, 3, 8, 6, 25, 30]	The productivity of a single-sloped solar still was found higher than a double-sloped solar still because a single-sloped solar still receives more radiation than a double-sloped solar still at low and high latitude stations.
	Water depth in basin [26–28, 27, 5, 29–31]	By increasing the water depth in the basin, the evaporative heat transfer coefficient decreases and consequently decreases the output
	Inclination of cover [32, 34–37, 47, 48, 6, 48–51]	The inclination and the direction of the cover depend on the latitude of the location The cover with inclination equal to a latitude angle will receive the solar radiation close to normal throughout the year.
	Type of solar still [2, 37–45]	The production of distilled water by taking the mirrors on the inside walls of the ASGHT still improved more than the SGHT
	Hybrid solar still [75–81]	The productivity of the coupled system is almost double that of the conventional solar still
	Stepped solar still [83–86]	To increase production per unit area by decreasing the thermal inertia of the water mass, this can be achieved in stepped solar still in which the area of the basin is minimized by having small trays
	The selection of the material [87–89]	Glass covers are preferred against the plastic ones
	Energy absorption and storing materials [90–92, 94–98]	The PCM is more efficient for lower masses of basin
	External and internal reflector [100–104]	Adding internal and/or external reflectors can be useful modification to increase the solar radiation incident on the basin liner as well as the productivity of the still.
	Sun tracking system [105–109]	Coupling a basin with a sun tracking system gave further improvement
	Insulation thickness [51, 59, 22]	Increasing the insulation thickness of the still increases the productivity
	Gap distance [40]	Reducing the gap distance between the water surface and the glass cover from 13.0 cm to 8 cm for the same cover slope increases the daily productivity by 11.0%
Operational parameters	**Coloring of water** [49–52]	The presence of a dye in the lower basin of the still was found able to increase the overall output.
	Water flow [53–59]	An increase or decrease in the yield with the increase or decrease in the heat transfer coefficient from the glass cover to the water flowing over it.
	Salt concentration [123, 124, 50]	The daily production decreases as the salt concentration increases
	Forced convection inside solar still [60]	The increase in the productivity of the solar still is mostly caused by the enhancement in the heat and mass transfer coefficients due to the existence of the air-vapor mixture motion inside the still.
	Binary mixture thermo-physical properties [61, 62]	Although the use of dry air properties leads to a large overestimation of the convective heat transfer coefficient, largely at the high temperature range of operation, the deviations related to the mass flow rates were moderate and led to up to approximately 10% maximum errors compared to the saturated mixture properties.
	Surfactant additives [63, 64]	An important possibility exists to enhance the water distillation process by surfactant additives

thought of as being more efficient when the dry air that is to be bubbled is kept hot, which will improve the whole process and increase productivity.

Finally, Table 2 summarizes briefly the results and conclusion of climatic-design-operational parameters affecting basin type solar distillation systems.

3. Cost analysis

The cost of potable water the production is affected by the location's energy cost. Energy consumption (2.25 MJ/kg for evaporation) and energy cost represent the most important contributions to the unit cost of desalinated water [132]. It is general knowledge that solar distillation is one of the more economical system as opposed to other distillation systems, due to the cost-free energy and reduced operating costs, especially in isolated areas [133]. What forms the bulk of the costs is usually the plexiglas container. The cost effectiveness of solar stills were confirmed by several other researches, where it was proven that drinkable water can be produced at affordable cost using solar stills. Fath et al. [132] suggested a figure of \$0.03/L (i.e. Rs. 1.20/L) for water produced from solar stills. Al-Hinai et al. [22] have inferred that the production cost of distillate to \$16.3/m^3 using a group of 250 conventional solar stills, and 52 weeks operational time. Kumar and Tiwari [134] have concluded that the cost of distillate water production as Rs. 1.93/L from hybrid (PVT) active solar still, during 269 clear days in a year. Wassouf et al. [135] designed and tested two prototypes Poly Vinyl Chloride (PVC) Pyramidal still and triangular-prism PVC solar still. It was estimated that the average cost per liter of water over a gauged useful life of 4 years was \$0.063/L for the triangular prism still, and \$0.046/L for the pyramidal still.

Due to the existence of different methods of cost estimation, it is not possible to determine a universal, comparable price per technology. Table 3 shows a short overview of the estimated costs for some solar stills presented in the previous section.

Table 3
Water prices of selected solar stills.

Technology	Country	Water price (us$/l)	Authors
Single-slope	Egypt	0.035	[132]
Double-slope	Oman	0.074	[22]
Hybrid (PVT) active solar still	India	0.048	[134]
The triangular prism still	Australia	0.063	[135]
Pyramidal still	Australia	0.046	[135]

4. Conclusion

This study highlights the factors that influence the output of solar stills. The most important factors include climate, design, and operational parameters. The productivity of the solar still was determined to be directly correlated to total solar radiation, ambient air temperature and wind speed. A lower glass angle generates higher output. In addition, the productivity of the still is inversely related to water depths, thickness of cover, gap distance between water surface and condensing cover increasing water absorptivity by using dyes, and increasing initial water temperatures. The addition of a passive condenser to the still increases the total yield to approximately 70%. Furthermore, integrating solar collector increases productivity by 36%. Integrating reflectors, whether internal or external, is rather useful as it increases the solar radiation onto the basin liner. It is reported that the daily distillate output of a basin type still could increase about 70–100%.

The maximum output increase was recorded at 98%, and this was the from a stepped solar still with additional fins and pebbles being placed in the basin. The annual distillate output from hybrid active solar still is found to be 3.5 times higher than a passive solar still. The ASGHT with mirrors on its inside walls was more efficient, and showed higher productivity than the SGHT. When the water depth in the basin was increased, the evaporative heat transfer coefficient decreases, consequently decreasing the output. The productivity of a single-sloped solar still was higher than its double-sloped counterpart, as the former receives more radiation compared to the latter at low and high latitude stations. At a particular flow rate, the evaporative heat transfer coefficient decreases with increasing water depth in the basin. Moreover, water distillation can be enhanced with surfactant additives. As the dust deposition increases, the transmittance reduction increases as well. The daily production is inversely proportional to salt concentrations, while forced circulation results in higher yields compared to thermo-siphon modes. Covers with an inclination that is equal to the latitude′s will receive more sun rays. The various materials like jute cloth, sponge, black cotton cloth and fins showed improvement to the distillate output. The productivity significantly increased in tandem with an increase of mass of the PCM, due to its heat storage capabilities. It was also surmised that a sun-tracking system trumps a fixed system in terms of still productivity.

Solar stills could be used to provide drinkable water at a reasonable cost. Due to the existence of different methods of cost estimation, it is not possible to determine a universal, comparable price per technology; the cost per liter of distilled water obtained from the basin type solar still ranged from 0.035–0.074$/liter. Finally, this study shows that the distillation productivity of a solar still is significantly affected by climatic, operational, and design parameters. Solar distillation output can be further improved through the operating and design conditions, as climatic conditions cannot be manipulated.

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